The Effect of Nitrogen Fertilizer Rates and Timing on Cranberry Yield and Fruit Quality

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Abstract. To examine the impact of N fertilizer rates and timing on cranberry (*Vaccinium macrocarpon* Ait.) yield and the fruit quality factors total anthocyanin, average berry weight, and field and storage rot, plots were established for 3 to 4 years. The cranberries received a total of 0, 22, or 44 kg N/ha over the growing season applied in three, four, or five applications, which varied by growth stage. There were eleven possible treatment combinations in Massachusetts on 'Early Black' and 'Howes' and in Wisconsin on 'Stevens' and 'Searles', and seven possible treatments in New Jersey on 'Early Black' and in Washington on 'McFarlin'. The results showed a nationwide response to N that suggests the experimental middle rate of 22 kg·ha⁻¹ would result in high yields with moderate rot. However, the best timing for applying the fertilizer varied by both state and cultivar, where three late season applications were best on 'Early Black' in New Jersey versus four early season applications on the same cultivar in Massachusetts, and applying N fertilizers across five applications was optimal for 'Stevens' in Wisconsin.

The American cranberry (*Vaccinium macrocarpon*) is a low-growing, nondeciduous woody perennial that sets fruit buds before overwintering. It is grown in a diversity of conditions throughout North America on commercial cranberry farms. The soil conditions on these sites ranges from high organic peat and muck soils to sandy mineral soils (Davenport and DeMoranville, 1993).

Over the past 25 years, there has been a yield increase in commercial cranberry beds. Average production in 1965 was 7.8 Mg·ha⁻¹ (Peterson et al., 1968). By 1990, the North American average was 16.8 Mg·ha⁻¹ (U.S. Dept. of Agriculture, 1990). Concomitant with the rise in yield has been a rise in the use of farm chemicals, fertilizers being among these (Deubert and Caruso, 1989).

Early studies of the impact of fertilizers on cranberry yield focused on blended fertilizers. When these studies were conducted, little to no fertilizer was regularly used by commercial farmers (Beckwith, 1919). Although these studies helped provide guidelines for cranberry farmers for fertilizer use, there still was little understanding of the impact of a given nutrient on the crop.

With the increased value of the cranberry crop, cranberry farmers began increasing their fertilizer applications to increase productivity. Today, the variability in fertilizer use between cranberry farmers is almost as great as the number of farmers. A study conducted on cranberries in Oregon has shown that different optimum rates and timings of N for 'Crowley' and 'Stevens' (Hart et al., 1990).

Nitrogen has been implicated in other studies on cranberries as an element associated with increases in crop yield (Eaton, 1971). Additionally, evidence indicates that excess N can lead to excessive vegetative production and, concurrently, reduce crop yield and quality (Eck, 1976). The relationship with fruit quality, particularly fruit rot, is of great importance for fresh fruit storability and marketing. This study was conducted to establish an optimal rate and timing strategy for N fertilizer use in cranberries.

Materials and Methods

In 1989, field trials were set up on two commercial cranberry farms in Massachusetts. On each farm, sets of plots were established on 'Howes' and 'Early Black', late and early producing cultivars, respectively. Blocks of plots containing 100 2 × 2-m plots were measured and marked with pin flags. Treatment assignments were completely random. The experiment consisted of 11 treatments to provide either 0, 22, or 44 kg N/ha over three, four, or five applications (Table 1), which were replicated six times. The number of plots in the block exceeded the total number needed so that unsuitable plots (e.g., plots with excessive weeds, lack of vine cover) could be avoided.

Nitrogen was applied as ammonium sulfate in the form of the commercial fertilizer 21–0–0. This was applied to each plot at the designated time with the use of a 500-mL plastic container with holes drilled into the lid. This shaker cup was used to sprinkle the fertilizer evenly throughout the plot. Application times were by growth stage and the following growth stages were used: bud-break, peak bloom, fruit set, bud set, and preharvest.

Each entire block of plots was also supplied with 66 kg·ha⁻¹ K and P fertilizers as commercial triple superphosphate (0–46–0) and potassium sulfate (0–0–50). The P and K applications were split across the five possible timings and were broadcast with a Cyclone spreader.

Fertilizer experiments were also initiated in 1990 in New Jersey, Wisconsin, and Washington. Table 2 lists the sites and cultivars per each growing area. The treatments were modified slightly for New Jersey and Washington, removing the preharvest fertilizer application (Table 1) to accommodate lower average yields and higher organic matter soils in those regions (Davenport and DeMoranville, 1993). Additionally, the number of replicates of each treatment was reduced to five. The total block of plots was reduced also, to 64 2 × 2-m plots in Wisconsin and 42 in New Jersey and Washington. Phosphorus and potassium application amounts were held uniform, but applied over one less application in Washington and New Jersey.

At the end of each growing season, fruit was hand harvested from two 900-cm² areas in each plot. The fruit from each 900-cm² area (the sample) were weighed to determine yield. A subsample of 100 random fruit was taken from each sample. The subsample was weighed to determine the average berry weight and evaluated for

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Table 1. Rates and timings (by growth stage) of N fertilizer applications and the states where the treatments were used.

N (kg·ha ⁻¹)	Applications (no.)	Times applied	State
0	Not applicable	Not applicable	MA, NJ, WA, WI
22	5	Budbreak, peak bloom, fruit set, bud set, preharvest	MA, WI
44	5	Budbreak, peak bloom, fruit set, bud set, preharvest	MA, WI
22	4	Peak bloom, fruit set, bud set, preharvest	MA, WI
44	4	Peak bloom, fruit set, bud set, preharvest	MA, WI
22	4	Budbreak, peak bloom, fruit set, bud set	MA, NJ, WA, WI
44	4	Budbreak, peak bloom, fruit set, bud set	MA, NJ, WA, WI
22	3	Peak bloom, fruit set, bud set	MA, NJ, WA, WI
44	3	Peak bloom, fruit set, bud set	MA, NJ, WA, WI
22	3	Budbreak, peak bloom, fruit set	MA, NJ, WA, WI
44	3	Budbreak, peak bloom, fruit set	MA, NJ, WA, WI

soundness to determine the percentage fruit rot. All samples were then stored at 4 °C. After 30- and 60-d intervals, the fruit were reevaluated for rot. At the end of 60 d, the two original samples from each plot were combined and a subsample of nonrotted fruit was taken. This subsample was frozen and analyzed for total anthocyanin (TAc) as a measure of fruit color (Fuleki and Francis, 1968).

The experiment was continued for 3 years in all locations but one. One of the Massachusetts sites (Bogs 2 and 4) had been saltwater flooded during Hurricane Bob on 19 Aug. 1991. The damage to the fruit at harvest was so severe that the fruit could not be accurately evaluated. The experiment was continued for a further growing season. Only Bog 2 with 'Early Black' was harvested from this site in 1992. Several replicates were not harvested because salt damage from the previous year had destroyed the growth. The cranberry farmer had harvested 'Howes' without notice before our harvest of Bog 4.

Data were analyzed using PROC GLM on PC SAS (SAS Institute, Cary, N.C.). Data from each year was analyzed separately to account for differences in climatic factors in each year.

Results and Discussion

Average berry weight and TAc. There was no overall impact of N rates or timing on average berry weight or TAc. In a few isolated instances there was a significant differences in each of these parameters based on either level of N applied or a combination of rate and timing. These instances were not consistent from year to year and do not provide any insights.

Nitrogen rates. The data from the years 1991 and 1992 were tabulated by rates of N applied and analyzed using a backwards stepwise regression procedure. After determining that yield and fruit rot varied by year and location, the data were sorted by year and location of plots—a combination cultivar and commercial

Table 2. Location of sites, cultivars studied, 5-year yield averages (1988–92), and the years in which the N fertilizer treatments were applied.

Bog (no.)	State	Cultivar	Years	5-Year yield avg (Mg·ha ⁻¹)
1	MA	Early Black	1989–91	11.71
2	MA	Early Black	1989–92 ^z	16.54
3	MA	Howes	1989–91	19.32
4	MA	Howes	1989–92 ^z	20.56
5	NJ	Early Black	1990–92	9.47
6	NJ	Early Black	1990–92	20.62
7	WA	McFarlin	1990–92	11.95
8	WI	Stevens	1990–92	19.54
9	WI	Searles ^y	1990–92	16.26
10	WI	Searles ^y	1990–92	17.34

^zPlots not harvested at one location in 1992 due to salt damage from flood. Experiment continued at this site a fourth year; however, 'Howes' were commercially harvested before scheduled experimental harvest, therefore, data were lost.

^yBogs 9 and 10 differed by soil type: Bog 9 was a mineral-based soil and Bog 10 was an organic soil.

Table 3. Cranberry yield and fruit rot levels after at least 3 years of receiving 0, 22, or 44 kg N/ha.

N (kg·ha ⁻¹)	Yield (Mg·ha ⁻¹)	Field rot (%)	Storage rot (%)	
			30 d	60 d
0	12.78	3.82	5.38	8.16
22	16.55	5.45	6.56	9.70
44	14.55	7.74	10.17	14.16
Significance	L*Q*	L***Q***	L***Q***	L***Q***

***Significant at $P \leq 0.05$ or 0.0005, respectively; L = linear, Q = quadratic.

grower—to evaluate the trends. The data were evaluated using linear and quadratic contrasts with SAS PROC GLM. For this section, rates of N will be referred to as kg N applied.

In 1992, at the end of the third harvest, yield and fruit rot showed an impact from N (Table 3). Yield was highest with 22 kg N. Field rot and 30 and 60 storage rots were increased by N (Table 3). Field rot increased with increasing N rates. Fruit rot increased after 30 and 60 d of cold storage, but in both cases, rot increased when N rates increased. Yield was influenced by the rate of N in 10 of the 15 possible year and location combinations (Table 4). In the 10 instances when yield was related to N rate, the response included a quadratic term, reflecting that yield did not simply increase with increasing N fertilizer additions.

Fruit rot (field and storage rots) was related to level of N (Table 4). The trend at 60 d echoes that at 30 d, so the data are not shown. In all cases, the lowest rot was at the 0 N level and highest at 44. The relationship between fruit rot and N rate showed a linear trend only in five cases, indicating an overall rise in rot as N rate

increased. In 13 of the bog and year combinations, there was also a quadratic response of rot to N rate. The average rot levels when a quadratic response occurred are for a larger increase in rot between the 22 and 44 N rates than between the 0 and 22 rates.

Overall, based on N rates alone, the data suggest that yield is optimized with 22 kg N/ha. This rate also has only a moderate amount of rot, at harvest and after 30 d storage. This indicates that 22 kg N/ha could be used as an optimal rate across regions and cultivars.

Nitrogen rates and timings. The timing of the fertilizer applications alone was not related to any of the parameters evaluated. However, a treatment effect (rate and timing) was found on all sites for some parameters.

For several bogs, yields were highest when no N was applied. This was found in 'Howes' in Massachusetts and 'McFarlin' in Washington (Table 5). At one location of 'Early Black' in New Jersey (Bog 5), for 2 consecutive years the 0 N treatment also showed a high yield. In all three of these cases, the beds are poor

Table 4. Cranberry yield, field rot, and storage rot after 30 d cold storage for cranberries receiving three different rates of total N over the growing season. Lack of data for Bogs 1 and 3 in 1992 are because the study for that site ended in 1991; for Bog 2 in 1991 missing data reflect fruit damage due to a hurricane.

Bog (no.)	N (kg·ha ⁻¹)	Yield (Mg·ha ⁻¹)		Field rot (%)		Storage rot (%) (%)	
		1991	1992	1991	1992	1991	1992
1	0	9.86		4		12	
	22	10.64		19		27	
	44	7.95		38		49	
	Significance	L*Q*		L***		L***	
2	0		18.26		4.33	4	
	22		19.38		8.18	8.6	
	44		17.36		14.04		14.4
	Significance		NS		L***Q***		L***Q***
3	0	25.87		16		38	
	22	19.49		26		39	
	44	17.02		30		40	
	Significance	L*,Q*		L*Q*		NS	
5	0	6.94	15.34	5	6.5	15	7.1
	22	6.16	12.77	24	15.6	39	16.4
	44	2.91	6.05	41	15.9	53	16.5
	Significance	L***Q***	L***Q**	L***	NS	L***	NS
6	0	8.18	13.33	5	2.1	7	2.4
	22	17.02	23.30	5	4.5	8	3.9
	44	11.76	22.74	12	8	20	7.4
	Significance	L***Q***	L**Q**	L***Q***	L***Q***	L***Q***	L**Q**
7	0	12.43	17.92	10	7.9	13	11.2
	22	11.65	15.12	11	10.2	15	13.4
	44	10.30	9.86	18	15.7	25	25.2
	Significance	NS	L***Q***	L*	L**Q**	L*Q*	L**Q**
8	0	20.72	11.09	4.5	0.51	5	2.2
	22	20.05	16.24	5.6	1.16	8	2.3
	44	24.08	16.91	6.6	1.61	10	4.1
	Significance	NS	L**Q**	NS	L*	L**Q**	L**Q**
9	0	18.59	11.65	3.3	2.9	3.9	5
	22	22.74	15.23	3.8	2.2	5.8	3.6
	44	23.52	19.49	3.5	2.6	5.7	6.4
	Significance	NS	L***Q***	NS	NS	NS	L*Q*
10	0	19.49	10.30	2.2	2.2	6.4	5.2
	22	24.08	14.78	3.6	3.6	7.1	3.8
	44	23.86	12.21	3.3	3.8	7.2	5.1
	Significance	NS	L***Q***	NS	NS	NS	NS

NS,*,*** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0005, respectively; L = linear, Q = quadratic.

Table 5. Average $\pm$ standard deviations for cranberry yield, field rot, and storage rot after 30 d cold storage for cranberries receiving three different rates of total N at different timings in the growing season. Lack of data for Bog 2 in 1991 reflect fruit damage due to a hurricane.

Bog (no.)	N (kg·ha ⁻¹)	Time applied ^z	Yield (Mg·ha ⁻¹)		Field rot (%)		Storage rot (%)	
			2nd yr	3rd yr	2nd yr	3rd yr	2nd yr	3rd yr
1	0	ALL	8.18 $\pm$ 2.14	9.86 $\pm$ 1.32	4 $\pm$ 1	3 $\pm$ 2	3 $\pm$ 2	12 $\pm$ 8
	22	ALL	11.42 $\pm$ 2.06	10.42 $\pm$ 7.18	19 $\pm$ 4	20 $\pm$ 5	15 $\pm$ 8	27 $\pm$ 11
	44	ALL	7.73 $\pm$ 2.32	7.50 $\pm$ 4.45	23 $\pm$ 12	32 $\pm$ 17	24 $\pm$ 13	47 $\pm$ 19
	22	4L	13.78 $\pm$ 8.12	10.64 $\pm$ 3.01	8 $\pm$ 5	18 $\pm$ 7	11 $\pm$ 7	27 $\pm$ 8
	44	4L	13.22 $\pm$ 2.42	9.18 $\pm$ 5.06	18 $\pm$ 7	33 $\pm$ 12	20 $\pm$ 5	43 $\pm$ 7
	22	4E	15.90 $\pm$ 4.98	8.29 $\pm$ 4.09	5 $\pm$ 4	15 $\pm$ 9	6 $\pm$ 4	26 $\pm$ 9
	44	4E	11.09 $\pm$ 1.65	7.17 $\pm$ 6.77	25 $\pm$ 5	44 $\pm$ 15	26 $\pm$ 8	54 $\pm$ 17
	22	3L	12.21 $\pm$ 2.33	14.45 $\pm$ 2.18	10 $\pm$ 3	22 $\pm$ 7	9 $\pm$ 4	28 $\pm$ 13
	44	3L	7.50 $\pm$ 2.05	8.62 $\pm$ 2.94	19 $\pm$ 5	35 $\pm$ 12	21 $\pm$ 8	40 $\pm$ 12
	22	3E	14.11 $\pm$ 4.09	8.96 $\pm$ 4.00	11 $\pm$ 4	19 $\pm$ 12	12 $\pm$ 9	22 $\pm$ 10
	44	3E	9.97 $\pm$ 2.03	7.50 $\pm$ 3.80	21 $\pm$ 2	48 $\pm$ 15	24 $\pm$ 4	63 $\pm$ 13
	Significance		*	NS	***	***	***	***
2	0	ALL		18.26 $\pm$ 2.98		4 $\pm$ 2		4 $\pm$ 1
	22	ALL		16.91 $\pm$ 4.67		5 $\pm$ 3		6 $\pm$ 3
	44	ALL		16.02 $\pm$ 5.88		13 $\pm$ 4		14 $\pm$ 4
	22	4L		19.26 $\pm$ 5.93		7 $\pm$ 3		9 $\pm$ 5
	44	4L		23.52 $\pm$ 2.57		12 $\pm$ 4		12 $\pm$ 5
	22	4E		17.58 $\pm$ 3.75		10 $\pm$ 5		10 $\pm$ 3
	44	4E		17.25 $\pm$ 5.00		14 $\pm$ 6		15 $\pm$ 2
	22	3L		19.49 $\pm$ 4.10		11 $\pm$ 7		11 $\pm$ 8
	44	3L		16.13 $\pm$ 4.49		15 $\pm$ 7		15 $\pm$ 4
	22	3E		23.52 $\pm$ 4.05		7 $\pm$ 3		7 $\pm$ 2
	44	3E		14.45 $\pm$ 4.26		16 $\pm$ 4		17 $\pm$ 6
	Significance			NS		*		***
3	0	ALL	13.89 $\pm$ 8.97	25.98 $\pm$ 14.43	8 $\pm$ 8	16 $\pm$ 6	9 $\pm$ 13	38 $\pm$ 22
	22	ALL	9.63 $\pm$ 4.65	20.72 $\pm$ 11.21	11 $\pm$ 7	21 $\pm$ 10	11 $\pm$ 8	30 $\pm$ 13
	44	ALL	4.82 $\pm$ 1.88	17.92 $\pm$ 5.87	14 $\pm$ 7	32 $\pm$ 6	16 $\pm$ 7	47 $\pm$ 6
	22	AL	8.96 $\pm$ 5.90	16.24 $\pm$ 10.35	12 $\pm$ 8	26 $\pm$ 12	13 $\pm$ 12	43 $\pm$ 13
	44	4L	6.72 $\pm$ 3.68	20.38 $\pm$ 8.36	15 $\pm$ 8	24 $\pm$ 12	19 $\pm$ 11	32 $\pm$ 9
	22	4E	10.08 $\pm$ 5.76	15.79 $\pm$ 7.02	10 $\pm$ 6	32 $\pm$ 14	13 $\pm$ 8	51 $\pm$ 17
	44	4E	7.84 $\pm$ 2.93	17.81 $\pm$ 3.92	13 $\pm$ 12	29 $\pm$ 14	21 $\pm$ 13	49 $\pm$ 13
	22	3L	8.18 $\pm$ 3.75	24.08 $\pm$ 10.16	9 $\pm$ 7	26 $\pm$ 11	13 $\pm$ 10	34 $\pm$ 11
	44	3L	6.72 $\pm$ 3.65	13.89 $\pm$ 5.71	13 $\pm$ 11	29 $\pm$ 11	15 $\pm$ 8	31 $\pm$ 8
	22	3E	5.71 $\pm$ 1.08	20.83 $\pm$ 9.80	10 $\pm$ 7	28 $\pm$ 14	12 $\pm$ 8	38 $\pm$ 16
	44	3E	5.49 $\pm$ 2.63	15.01 $\pm$ 6.09	15 $\pm$ 6	33 $\pm$ 12	17 $\pm$ 12	45 $\pm$ 15
	Significance	**	NS	NS	NS	NS	NS	
5	0	ALL	6.94 $\pm$ 4.91	16.46 $\pm$ 6.96	5 $\pm$ 3	7 $\pm$ 6	15 $\pm$ 4	7 $\pm$ 5
	22	ALL	3.58 $\pm$ 2.34	12.32 $\pm$ 4.06	25 $\pm$ 12	14 $\pm$ 14	39 $\pm$ 14	14 $\pm$ 15
	44	ALL	5.26 $\pm$ 3.29	8.62 $\pm$ 6.96	46 $\pm$ 24	18 $\pm$ 7	59 $\pm$ 11	19 $\pm$ 9
	22	3L	5.94 $\pm$ 1.99	14.00 $\pm$ 8.65	30 $\pm$ 12	18 $\pm$ 8	41 $\pm$ 10	20 $\pm$ 9
	44	3L	2.69 $\pm$ 1.22	2.46 $\pm$ 1.40	36 $\pm$ 11	13 $\pm$ 13	54 $\pm$ 13	13 $\pm$ 6
	22	3E	7.50 $\pm$ 2.90	11.89 $\pm$ 4.01	16 $\pm$ 9	15 $\pm$ 8	35 $\pm$ 16	15 $\pm$ 12
	44	3E	2.35 $\pm$ 0.52	7.06 $\pm$ 5.48	42 $\pm$ 19	16 $\pm$ 16	45 $\pm$ 20	18 $\pm$ 16
	Significance	*	**	***	NS	***	NS	
6	0	ALL	8.29 $\pm$ 2.37	13.33 $\pm$ 3.17	5 $\pm$ 2	2 $\pm$ 1	7 $\pm$ 2	2 $\pm$ 1
	22	ALL	15.90 $\pm$ 5.58	23.74 $\pm$ 3.94	5 $\pm$ 3	6 $\pm$ 6	8 $\pm$ 6	5 $\pm$ 6
	44	ALL	14.00 $\pm$ 7.04	26.66 $\pm$ 6.16	10 $\pm$ 5	10 $\pm$ 4	15 $\pm$ 6	10 $\pm$ 6
	22	3L	17.47 $\pm$ 4.69	22.18 $\pm$ 8.01	8 $\pm$ 3	5 $\pm$ 4	12 $\pm$ 4	4 $\pm$ 3
	44	3L	9.30 $\pm$ 3.93	20.83 $\pm$ 2.85	13 $\pm$ 6	7 $\pm$ 8	21 $\pm$ 9	6 $\pm$ 7
	22	3E	17.81 $\pm$ 2.88	24.08 $\pm$ 5.75	3 $\pm$ 2	2 $\pm$ 1	4 $\pm$ 3	3 $\pm$ 1
	44	3E	11.87 $\pm$ 4.60	20.61 $\pm$ 5.78	11 $\pm$ 6	7 $\pm$ 5	23 $\pm$ 10	6 $\pm$ 4
	Significance	**	**	***	NS	***	NS	
7	0	ALL	12.43 $\pm$ 2.49	17.92 $\pm$ 2.29	10 $\pm$ 7	8 $\pm$ 8	14 $\pm$ 8	11 $\pm$ 9
	22	ALL	12.10 $\pm$ 2.83	14.70 $\pm$ 4.26	9 $\pm$ 4	7 $\pm$ 5	13 $\pm$ 7	8 $\pm$ 6
	44	ALL	10.30 $\pm$ 3.98	9.74 $\pm$ 4.76	16 $\pm$ 15	17 $\pm$ 9	27 $\pm$ 17	27 $\pm$ 12
	22	3L	10.86 $\pm$ 3.81	16.46 $\pm$ 3.74	11 $\pm$ 6	13 $\pm$ 8	16 $\pm$ 10	19 $\pm$ 11

Table 5. Continued.

Bog (no.)	N (kg·ha ⁻¹)	Time applied ^z	Yield (Mg·ha ⁻¹)		Field rot (%)		Storage rot (%)	
			2nd yr	3rd yr	2nd yr	3rd yr	2nd yr	3rd yr
7	44	3L	10.30 ± 3.57	10.42 ± 4.89	18 ± 8	16 ± 5	23 ± 8	28 ± 15
	22	3E	11.87 ± 4.78	14.11 ± 2.45	14 ± 7	10 ± 6	17 ± 8	13 ± 7
	44	3E	10.19 ± 5.62	9.63 ± 6.47	19 ± 16	15 ± 10	25 ± 16	20 ± 10
	Significance	NS	*	NS	NS	NS	*	
8	0	ALL	20.72 ± 2.38	10.30 ± 3.54	4 ± 4	0.5 ± 0.3	5 ± 4	2.3 ± 1.3
	22	ALL	21.17 ± 4.34	16.80 ± 1.88	5 ± 1	0.8 ± 0.6	6 ± 1	1.4 ± 0.9
	44	ALL	22.74 ± 8.23	13.66 ± 3.54	10 ± 3	1.3 ± 0.9	13 ± 3	1.9 ± 0.8
	22	4L	19.49 ± 7.32	15.01 ± 3.54	8 ± 3	0.7 ± 0.5	11 ± 4	1.3 ± 0.8
	44	4L	22.74 ± 5.87	14.22 ± 1.99	5 ± 2	0.8 ± 0.3	8 ± 3	3.4 ± 2.1
	22	4E	21.26 ± 8.10	13.66 ± 2.71	4 ± 4	0.9 ± 0.5	9 ± 6	2.4 ± 1.3
	44	4E	27.66 ± 6.82	10.86 ± 3.08	6 ± 3	0.8 ± 0.5	10 ± 3	3.8 ± 2.9
	22	3L	16.91 ± 4.73	15.34 ± 3.30	6 ± 2	0.9 ± 0.1	9 ± 4	2.4 ± 1.6
	44	3L	21.62 ± 4.33	13.78 ± 2.51	4 ± 2	1.1 ± 0.9	8 ± 2	8.1 ± 4.4
	22	3E	21.73 ± 6.63	12.66 ± 5.04	4 ± 3	1.0 ± 0.9	7 ± 5	3.4 ± 2.0
	44	3E	25.87 ± 3.62	8.51 ± 1.61	8 ± 5	0.9 ± 0.4	10 ± 3	3.0 ± 1.6
	Significance	NS	***	*	NS	*	***	
9	0	ALL	18.59 ± 4.15	11.09 ± 2.64	3 ± 1	3 ± 2	4 ± 1	5 ± 2
	22	ALL	21.28 ± 5.78	15.79 ± 5.88	3 ± 1	4 ± 2	6 ± 1	5 ± 2
	44	ALL	21.62 ± 5.48	15.57 ± 4.57	3 ± 1	2 ± 0.5	5 ± 1	5 ± 2
	22	4L	20.61 ± 11.88	15.01 ± 1.60	5 ± 3	2 ± 1	6 ± 3	3 ± 1
	44	4L	27.22 ± 6.14	16.58 ± 5.17	3 ± 1	3 ± 1	6 ± 1	7 ± 3
	22	4E	20.16 ± 6.36	18.82 ± 3.40	3 ± 1	2 ± 1	5 ± 1	3 ± 0.5
	44	4E	24.53 ± 1.5	17.02 ± 1.97	5 ± 0.5	3 ± 2	7 ± 1	5 ± 2
	22	3L	24.42 ± 5.34	16.46 ± 2.79	4 ± 1	2 ± 1	6 ± 2	3 ± 2
	44	3L	20.16 ± 2.93	19.49 ± 4.80	2 ± 1	3 ± 3	4 ± 1	9 ± 7
	22	3E	27.33 ± 3.21	14.90 ± 4.20	4 ± 1	1 ± 0.5	6 ± 1	3 ± 1
	44	3E	24.19 ± 6.14	16.24 ± 2.25	4 ± 2	2 ± 1	7 ± 3	6 ± 3
	Significance	NS	NS	NS	NS	**	**	
10	0	ALL	19.49 ± 5.47	11.65 ± 3.30	2 ± 1	4 ± 2	6 ± 1	5 ± 2
	22	ALL	23.97 ± 5.90	18.70 ± 7.61	3 ± 3	2 ± 1	10 ± 2	4 ± 3
	44	ALL	23.52 ± 2.55	17.36 ± 6.62	3 ± 2	3 ± 1	8 ± 3	4 ± 1
	22	4L	23.74 ± 3.08	12.99 ± 5.42	3 ± 1	2 ± 3	7 ± 2	3 ± 2
	44	4L	22.29 ± 2.98	22.62 ± 6.82	4 ± 2	6 ± 3	6 ± 2	7 ± 4
	22	4E	22.74 ± 4.79	16.24 ± 2.77	2 ± 1	2 ± 1	7 ± 2	4 ± 1
	44	4E	21.26 ± 5.04	19.26 ± 6.33	3 ± 0.5	3 ± 1	7 ± 2	5 ± 1
	22	3L	23.86 ± 2.88	11.20 ± 3.74	3 ± 2	3 ± 2	5 ± 3	5 ± 2
	44	3L	28.00 ± 4.17	17.02 ± 2.65	4 ± 1	2 ± 1	9 ± 3	3 ± 2
	22	3E	26.21 ± 6.16	16.02 ± 4.78	4 ± 2	1 ± 0.5	6 ± 3	2 ± 1
	44	3E	24.53 ± 5.32	22.51 ± 2.54	3 ± 1	5 ± 2	9 ± 4	6 ± 3
	Significance	NS	**	**	**	*	*	

^zL = late, E = early.NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0005, respectively.

producers, as evidenced by the low yields under all treatments and from previous yield history records (Table 2). These results indicate that, in low yield situations, N fertilizers are not advantageous for crop production.

At the same locations where yield was highest with 0 N, fruit rot showed slightly different patterns (Table 5). 'Howes' showed no difference in any of the rots by treatment in any year or at either of the two locations. In Washington, 'McFarlin' only showed a difference in rot at 30 d in 1992. The 22 rate applied in four applications gave the lowest level of rot. However if 44 kg N/ha was applied over the same timing, the rot level was highest.

'Early Black' in Massachusetts only showed a difference in yield with different rates and timings in 1 year. The data indicate that the 22 rate gave the best yield when applied in four early season

applications (Table 5). 'Early Black' in Massachusetts consistently showed the lowest rot with the 22 kg N rate in four early applications at Bog 1 and five applications at Bog 2. The 44 rate in four early applications was one of the treatments with highest rot at both locations.

In New Jersey, the same cultivar showed a different response. At both locations, in high- and low-yielding beds, applying N fertilizer at 22 kg·ha⁻¹ in three early or three late applications resulted in the highest yields on plots that received N in 1991 and 1992. 'Early Black' at both locations in New Jersey showed the lowest field and storage rot levels in plots receiving N when 22 kg N/ha was applied in three late applications. Applications of 44 kg N/ha in three early applications gave the highest rot at both locations.

'Stevens' in Wisconsin only showed a significant difference in yield by timing in 1992, the third year of the experiment. In this case, applying the fertilizer at 22 kg N/ha in five applications throughout the growing season was distinctly the best treatment. Applying 22 kg N/ha in either five or three early applications were the only treatments with consistently low rot plus high yields in 'Stevens'.

Results with 'Searles' also in Wisconsin, were less clear than those with 'Stevens'. At one location, Bog 9, none of the treatments showed a yield increase. Bog 9 was a mineral-based soil. In the final year, a yield increase was found at the second location (Bog 10). The highest average yield was with the 44 kg N/ha rate over three early or four late applications. That crop year, 1992, was a very cold year in this region of Wisconsin (W. Bland, personal communication). The site that showed the highest yield with two timings at the 44 rate was a muck soil. It is likely that the cold weather resulted in very little N mineralization from the soil, thus, the higher rate of N gave the two best treatments. For 'Searles' grown on mineral and organic soils, the 22 rate in three late applications had relatively consistent low rot at 0 and 30 d. Several treatments had high rots, but these were not consistent.

Conclusions

Across all of the cultivars examined in this study, the yield and rot (field and storage) response to N suggests that low to moderate N applications are suitable for cranberries over a variety of conditions. The specific timings of these fertilizers varied by cultivar and state.

In Massachusetts, the evidences for rates and timing on 'Howes' was inconclusive. In the final year at one location, the bed was commercially harvested before research sample collection. However, with the data from this study, no specific timings for N application can be suggested.

'Early Black' in Massachusetts shows a distinctive rate and timing regime. Applying 22 kg N/ha in four equal applications in the early season (budbreak, peak bloom, fruit set, and bud set) had the highest yield and lowest rot levels, suggesting that this treatment would be optimal for 'Early Black' production in Massachusetts. The same cultivar in New Jersey, on high- and low-yielding beds, showed optimal productivity at the same N rate, but applied over three late season applications (peak bloom, fruit set, bud set),

since plots fertilized with this treatment had high yields and low rot levels compared to all other fertilized plots. Although, the control (0 N) treatment had the highest yield on the low-producing bog (Bog 5), the response over the period of this experiment suggests that in the long-term production will decrease if N is withheld.

In Wisconsin, the evidence for 'Searles' was inconclusive. The treatment that showed highest yield did so only in 1 year. Also, this treatment did not have good fruit quality. Thus, no single treatment suggests itself as the optimal from this experiment. For 'Stevens', the optimal was 22 kg N/ha in five equal applications at budbreak, peak bloom, fruit set, bud set, and preharvest. This treatment showed high yield and low rot and thus optimized cranberry yield.

Overall, the results of this study indicate that cranberries produce optimally when fertilized at the experimental middle rate of 22 kg N/ha. This rate holds consistently across years. However, the optimal timing for the N applications varied to some extent. Thus, optimal N fertilizer timing in cranberries varied by cultivar and within growing region and may vary by year.

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